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(54) Programmed reference.

(57) A programmable reference used to identify a state of an array cell in a multi-density or low voltage supply flash EEPROM memory array. The programmable reference includes one or more reference cells, each reference cell having a floating gate which is programmed to control its threshold value. The array cells are read by applying an identical voltage to the gate of the array cell and the reference cell and comparing outputs to determine the array cell state. During read of an array cell, the programmable reference cell is biased the same as the array cell, so that the difference in threshold values between reference cells and array cells remain constant with a change in V_{cc}. Circuitry is included for programming the reference cells utilizing a simple resistor ratio. Programming is performed at test time, preferably by the manufacturer, to assure V_{cc} remains within strict tolerances. The array cells are programmed and read without resistor biasing and under looser tolerances using the reference cells at a later time.

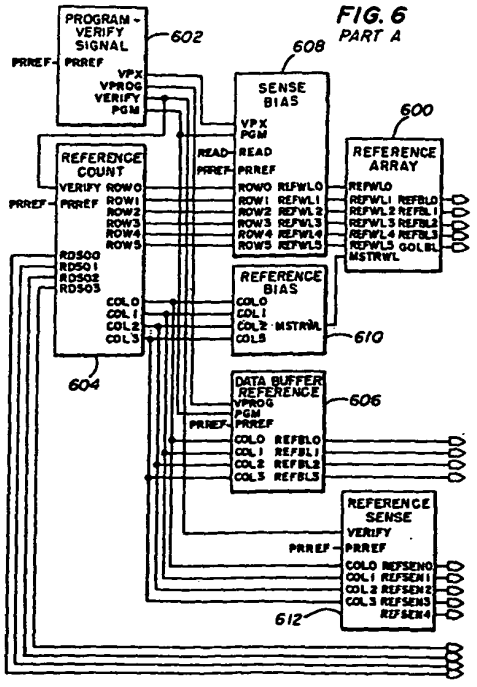

FIG. 6
PART A

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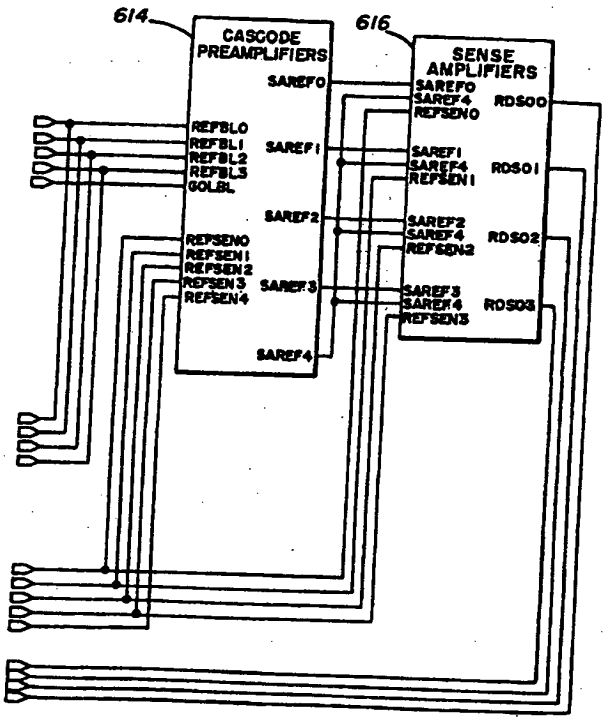
FIG. 6
PART B


614
CASCODE PREAMPLIFIERS
REFBL0
REFBL1
REFBL2
REFBL3
GOLBL
REFSEN0
REFSEN1
REFSEN2
REFSEN3
REFSEN4
SAREF0
SAREF1
SAREF2
SAREF3
SAREF4
616
SENSE AMPLIFIERS
SAREF0
SAREF4
REFSEN0
RDS00
SAREF1
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REFSEN1
RDS01
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REFSEN2
RDS02
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SAREF4
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RDS03

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 30 8288

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	WO-A-90 12400 (SUNDISK CORPORATION) * the whole document *	1-10, 17-19, 21-25	G11C16/06 G05F3/24 G11C11/56
A		11-16,20	
X	EP-A-0 409 697 (GEMPLUS CARD INTERNATIONAL) * the whole document *	1,3-6	
A		8	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

G11C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	14 June 1995	Degraeve, L

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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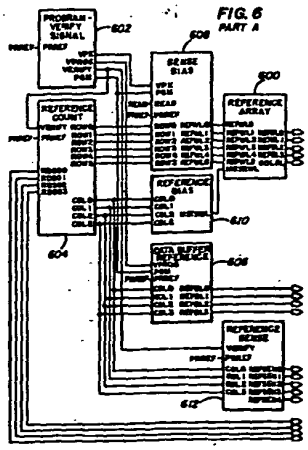

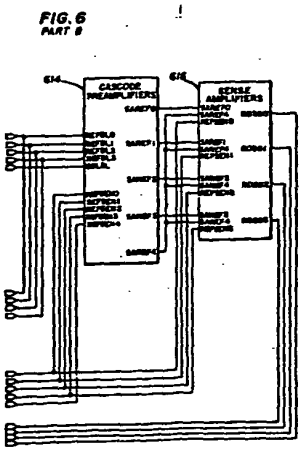

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The present invention relates in general to a reference means for memory arrays, and more particularly to a reference means which may be utilized to determine the thresholds of flash electrically erasable programmable read only memory (EEPROM) cells utilized in low voltage supply and multi-density memory arrays.

One traditional referencing scheme utilized to determine the threshold of a memory cell includes an unprogrammed reference cell coupled with a sense ratio. Fig. 1 shows such a reference cell 100 coupled with a sense ratio to provide a reference for an array cell 102. The sense ratio is provided by two parallel resistive elements 112 and 114, having the same value R connected between V_{cc} and the drain of array cell 100, and an additional resistive element 116, of value R, connected between V_{cc} and the drain of array cell 102. The drain of reference cell 100 provides a reference output to one input of comparator 104. The drain of array cell 102 provides an array cell output to a second input of comparator 104. The output of comparator 104 indicates the threshold state of array cell 102.

To read the states of the array cell 102 in Fig. 1, V_{cc} is applied to the gates of reference cell 100 and array cell 102. When V_{cc} is applied, the sense ratio will vary the voltage seen by comparator 104 at the drain of reference cell 100 as compared to the drain of array cell 102. The voltage seen by comparator 104 at the drain of reference cell 100 is, thus, V_{cc}-1/2RI_D, whereas the voltage seen by the comparator at the drain of array cell 102 is V_{cc}-I_DR. I_D is controlled by the thresholds, v_t, of the reference cell 100 and array cell 102 as seen by the saturation equation for a MOS transistor $I_D = K(v_{GS} - v_t)^2$, where v_{GS} here is equal to V_{cc}. With both the reference cell 100 and array cell 102 unprogrammed, or having an identical threshold v_t, the sense ratio will provide a higher voltage at the reference output to comparator 104 than the array cell output causing comparator 104 to output a first state. With the array cell programmed to have a threshold raised to a certain level, I_D for the array cell will be reduced and the voltage of the array cell output will rise above the voltage at the reference cell output causing comparator 104 to output a second state.

Because the sense ratio method utilizes differing resistor ratios connected to the drains of the reference cell and the array cell, the sense ratio method provid s a reference output varying with respect to an array cell output due to temperature and process variations of the resistive elements as well as variations in V_{cc}.

The circuitry of Fig. 3 illustrates another traditional r f rencing scheme called a bias gate method. The bias gate method provides a more accurate refer nce than the sense ratio method because the effect of process, temperatur and V_{cc} variations are reduced with respect to the sense ratio method. The circuitry of Fig. 3 includes an unprogrammed reference cell 100, an array cell 102, and a comparator 104 similar to the sense ratio circuitry of Fig. 2. For convenience, in Fig. 3 and subsequent drawings reference numbers used to identify components carried over from previous drawings are likewise carried over.

Unlike the sense ratio method of Fig. 2 which provides a resistor ratio connected to the drains of reference cell 100 and array cell 102 directly, the circuitry of Fig. 3 has a resistor ratio connected to the gate of reference cell 100 to vary V_{GS}. The resistor ratio is provided by resistive element 302 connected between V_{cc} and the gate of reference cell 100 along with a resistive element 304 connecting the gate of reference cell 100 to ground. The drain of reference cell 100 provides a reference output to one input of comparator 104. The drain of array cell 102 provides an array cell output to a second input of comparator 104. Identical resistive elements 306 and 308 connect V_{cc} to the reference and array cell outputs to convert their I_D output to a voltage at the inputs of comparator 104. By varying v_{GS} instead of directly varying I_D, process and temperature effects on the resistive elements and V_{cc} variations cause less variation between the reference cell and array cell outputs than with the sense ratio method.

To read the state of the array cell 102 in Fig. 3, a voltage, V_{cc}, is applied directly to the gate of array cell 102 while being applied through resistive elements 302 and 304 to the gate of reference cell 100. With both the reference cell 100 and array cell 102 unprogrammed, or having an identical v_t, resistive elements 302 and 304 will provide a lower v_{GS}, and thus a lower I_D at the reference cell output to comparator 104 than the current at the array cell output causing comparator 104 to indicate a first state. With the array cell programmed to have a threshold raised to a certain level, the array cell output will rise above the reference cell output causing comparator 104 to output a second state.

With reference schemes such as the sense ratio and bias gate schemes, variations of the reference output with respect to the array cell output due to process, temperature and V_{cc} variations can cause read errors. The potential for error is more significant with memories having a low working margin between array cell threshold states such as in multi-density or low voltage supply memories. Fig. 2 shows the reference levels and array cell threshold states for a typical multi-density memory configured to be single density, 3/2 density and double density. As indicated, as the density is increased, the working margin between reference levels and array cell states decreases. For in-

stance, utilizing single density, the margin between the 0 state and the reference state is (4.00-2.9V = 1.10V.) With 3/2 density, the margin is reduced by 50% (4.00V-3.45V = 0.55V), and for double density the margin is reduced to 0.33V. The working margin in low voltage supply memories is limited because a reduction in V_{cc} limits the range available for array cell threshold states. With a low working margin, a reference is needed which tracks variations in the electrical characteristics of an array cell to reduce potential errors.

We will describe a referencing scheme with a reference which tracks the variations in the electrical characteristics of an array cell.

We will describe a programmable reference including one or more reference cells, each reference cell having a floating gate which is programmed in a controlled environment to set its threshold value. To read the state of an array cell, an identical voltage, V_{cc}, is applied to the gate of an array cell and the reference cell. Additionally, the outputs of the array cell and the reference cell are maintained under the same bias conditions. During read, the reference cell drain provides an output which is compared with an array cell drain output to determine the threshold of the array cell with respect to the threshold of a reference cell.

The described arrangement further includes circuitry for programming the reference cells utilizing the bias gate method for biasing with respect to an unprogrammed cell. The reference cells are programmed at test time, preferably by the manufacturer, to assure V_{cc} and temperature remain within strict tolerances to eliminate variations when programming the reference thresholds using the bias gate method. The array cells are then programmed and read under looser V_{cc} and temperature tolerances using the reference cells thereafter.

During read of an array cell, the reference cells and array cells are maintained under the same bias conditions rather than using a sense ratio or a biased gate method, thus reducing the effect of process variations on the reference and array cell outputs. Because V_{cc} is applied as a read voltage identically to the gate of a reference cell and an array cell, the working margin between the reference cell and array cell outputs remains substantially constant with changes in V_{cc}. To assure the changes in threshold values remain constant with temperature, the array cells and reference cells are also preferably included as core cells on the same integrated circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

Further details of the present invention are explained with the help of the attached drawings in which:

Fig. 1 shows circuitry for providing a reference for a memory array using a sense ratio method;
Fig. 2 shows the reference levels needed for a single density, a 3/2 density and double density memory;
Fig. 3 shows circuitry for providing a reference for a memory using a bias gate method;
Fig. 4 shows an array cell along with programmable reference cells of the present invention utilized to read the array cell;
Fig. 5 shows a block diagram of circuitry utilized to program an array cell as well as reference cells utilized during program and read of the array cell;
Fig. 6 illustrates an embodiment of the programmed reference of the present invention designed for a 3/2 density memory array;
Fig. 7 shows circuitry for the reference cells and the golden reference of the reference array shown in Fig. 6;
Fig. 8 shows circuitry for the reference count circuit shown in Fig. 6;
Fig. 9 shows circuitry for shift registers utilized in Fig. 8;
Fig. 10 shows circuitry for the data buffer reference circuit shown in Fig. 6;
Fig. 11 shows circuitry for the sense bias circuit shown in Fig. 6;
Fig. 12 shows circuitry for the reference bias circuit shown in Fig. 6;
Fig. 13 shows circuitry for the reference sense circuit shown in Fig. 6;
Fig. 14 shows circuitry for one of the cascode preamplifiers utilized in the circuitry of Fig. 6; and
Fig. 15 shows circuitry for one of the sense amplifiers utilized in the circuitry of Fig. 6.

DETAILED DESCRIPTION

Fig. 4 shows an array cell 400 along with programmable reference cells 402-1 through 402-(n-1) of the present invention utilized to read array cell 400. Array cell 400 is read by applying a word address which is decoded in word select circuit 404 to provide a select voltage V_{SEL} to the gate of array cell 400. The select voltage is identically applied to the gates of reference cells 402-1 through 402-(n-1). V_{SEL} may be V_{cc}, V_{DD}, or a boosted gate voltage as disclosed in U.S. Patent Application Setial No. 08/ 160578 entitled "Boosted and Regulated Gate Power Supply With Reference Tracking for Multi-Density and Low Voltage Supply Memories" by the present inventors filed on December 1, 1993, incorporated herein by reference (our reference HRW/BEP/AMD939. The output of array cell 400 is connected with one or more outputs of reference cells 402-1 through 402-(n-1)

of the present invention to a comparison circuit 406. Comparison circuit 406 outputs a signal indicating the state of array cell 400.

Although array cell 400 is shown as a transistor with a floating gate having a programmable threshold, array cell 400 may be a ROM transistor having a fixed threshold. Array cell 400 stores one of n threshold values indicative of states such as the 0 0 state, the 0 0.5 state or 1 1 state of the 3/2 density cell as shown in Fig. 2.

The reference cells 402-1 through 402-(n-1) each have a floating gate which stores an electrical charge which may be programmed to set a reference threshold value. A total of n-1 reference cells are utilized which are each programmed to a successive threshold level, such as reference states A and B of the 3/2 density cell of Fig. 2. By similarly biasing reference cells 402-1 through 402-(n-1) and the array cell 400 and applying an identical voltage, V_{SEL}, to their gates, the thresholds of reference cells 402-1 through 402-(n-1) can be compared with the array cell 400 threshold.

Comparison circuitry 406 compares the thresholds by comparing the output of the array cell 400 to the outputs of reference cells 402-1 through 402-(n-1) when the select voltage V_{SEL} is applied. Typical circuitry for the comparison circuitry 406 is shown in U.S. Patent No. 5,218,569 by Banks entitled "Electrically Alterable Non-volatile Memory With N-Bits Per Memory Cell" and U.S. Patent No. 4,495,602 by Sheppard entitled "Multi-bit Read Only Memory Circuit, both incorporated herein by reference. The comparison circuitry 406 outputs comparison results as a digital signal having the number of bits capable of being identified by threshold states storable by array cell 400.

Fig. 5 shows a block diagram of circuitry connected to program array cell 400 as well as reference cells 402-1 through 402-(n-1) and 502-1 through 502-n of the present invention utilized to program array cell 400. Array cell program-verify circuit 504 is provided to program array cell 400 while reference cell program-verify circuit 506 is provided to program the reference cells. Reference cells 502-1 through 502-n have programmable threshold values each programmed to one of the n states such as the 0 0 state, 0 0.5 state, or the 1 1 state as shown for a 3/2 density cell in Fig. 2, the states being between states such as states A and B of the 3/2 density design which are storable by reference cells 402-1 through 402-(n-1).

Array cell program-verify circuit 504 is connected to the gate and drain of array cell 400 to program array cell 400. Array cell program-verify circuit 504 is also connected to the drains of reference cells 502-1 through 502-n to compare the array and reference cell outputs to determine if array c ll 400 is properly programmed. Typical circuitry for an array cell program-verify circuit 504 along with the method utilized to program a multi-density cell is shown and described in U.S. Patent No. 5,218,569 by Banks as cited previously.

Reference cell program-verify circuit 506 is connected to the gates and drains to allow programming of reference cells 402-1 through 402-(n-1) as well as reference cells 502-1 through 502-n. The reference cell program-verify circuit 506 utilizes traditional methods to supply program and verify voltages to enable programming of the reference cells. The reference program-verify circuitry 506 further utilizes circuitry for biasing each reference with respect to an unprogrammed cell utilizing the bias gate method to verify proper programming. Circuitry is further provided to sequence through each of the reference bits to enable a proper bit line and word line of a reference cell being programmed.

Reference program-verify circuitry 506 is utilized to program the references at test time, preferably by the manufacturer, so that V_{cc} and temperature remain within strict tolerances to eliminate variations in setting reference thresholds when utilizing the biased gate method. Array program-verify circuit 504 is utilized at a later time to program the array cells using looser V_{cc} and temperature tolerances.

Fig. 6 illustrates an embodiment of the programmed reference of the present invention designed for a 3/2 density memory array as shown in Fig. 2. Fig. 6 includes components which make up the reference cell program-verify circuitry 506 of Fig. 5 along with a reference array 600 containing reference cells to be programmed. To reduce the amount and complexity of circuitry required to program the reference cells, the circuitry of Fig. 6 is designed to program the reference cells one cell at a time.

The circuit of Fig. 6 includes program-verify signal circuitry 602 which, upon receiving a PRREF signal indicating that references are to be programmed, alternately produces program and verify signals to program an individual reference cell. A program voltage applied to the drain of a reference cell during program is supplied as the signal VPROG. A signal VPX alternately carries a program voltage and a verify voltage to the gate of a reference cell to program the reference cell. VPX carries a read voltage during reading or verifying the programming of array cells. During verify, a signal VERIFY is asserted. During program a signal PGM is asserted. Traditional circuitry for programming a single floating gate memory cell can be utilized to provide the program-verify signal circuitry 602. Such traditional circuitry is generally described in U.S. Patent No. 5,218,569 by Banks as discussed previously.

To sequence through all the reference cells and direct the program and verify voltages to a selected cell, control logic is provided to enable a proper reference bit line and reference word line. The control logic consists of a reference count circuit 604 along with some mixed logic. Reference count circuit 604 begins sequencing upon receipt of the PRREF signal and provides a column signal (COL0-COL3) and a row signal (ROW0-ROW5) to indicate which reference cell is to receive program and verify voltages. Reference count circuit 604 sequences to a next reference cell bit when a signal RDSO-RDSO3 and VERIFY are provided indicating the previous cell has been properly programmed.

The data buffer reference 606 and sense bias circuit 608 decode the column and row signals output by reference count circuit 604 to provide the program and verify voltages to a selected reference cell. The data buffer reference 606, upon receiving PRREF and PGM, decodes the column signal (COL0-COL3) to direct the program voltage signal VPROG on one of reference bit lines (REFBL0-REFBL3) to the drains of a column of r ference cells in reference array 600. The sense bias circuit 608, upon receiving PRREF, decodes the row signal (ROW0-ROW3) to direct the program and verify voltage signal VPX on one of reference word lines (REFWL0-REFWL5) to the gates of a row of reference cells in reference array 600. Sense bias circuit 608 also receives a read signal to apply VPX to all the wordlines during read or verify of an array cell. PGM is received to disable the sense bias circuit 608 during programming of an array cell.

One bit in reference array 600 is provided as a reference for programming the reference bits. This bit is referred to as the golden reference. To bias the gate of the golden reference utilizing the bias gate method, one of several resistor ratios provided by reference bias circuit 610 can be connected on a master word line (MSTRWL) to the gate of the golden reference. The particular resistor ratio of reference bias circuit 610 is controlled by the column signal (COL0-COL3) received from reference count circuit 604.

To verify if a reference signal has been properly programmed, the program reference includes ref rence sense circuit 612, cascode preamplifiers 614, and sense amplifiers 616. When VERIFY and PRREF are asserted, the reference sense circuit 612 decodes the column signal (COL0-COL3) to provide an enable signal (REFSEN0-REFSEN4) to enable proper cascode preamplifiers of circuitry 614 and sense amplifiers of circuitry 616. The enabled cascode preamplifier of circuit 614 is connected to receive a current from the bit line (REFBL0-REFBL3) of the reference cell being programmed to provide an enabled reference cell output voltage (SAREF0-SAREF3). An additional cascode preamplifier of circuit 614 is connected to receive a current from the bit line (GOLBL) of the golden reference to provide a golden reference output voltage (SAREF4) when an enabling signal (REFSEN0-REFSEN4) is received. The enabled sense amplifier of circuit 616 compares the enabled reference cell output voltage (SAREF0-SAREF3) to the golden reference output voltage (SAREF4) and outputs a signal (RDSO0-RESO3) indicating if the enabled reference cell output voltage and the golden reference cell output voltage are substantially equal.

Detailed circuitry for the components of Fig. 6 are shown in subsequent figures which are described below.

Reference Array 600

Fig. 7 shows circuitry for the reference cells and the golden reference of the reference array 600 shown in Fig. 6. Word line connections (REFWL0-REFWL5) are provided to the gates of the reference cells and bit line connections (REFBL0-REFBL3) are provided to drains of the reference cells. The reference cells have floating gates which may be programmed to a predetermined threshold value.

The circuitry of Fig. 6 includes a total of twenty-four reference cells as required for a 3/2 density design having an eight bit output. As seen from the 3/2 density design values in Fig. 2, four reference cells are required to provide four reference cell bit line outputs to an array cell. Two reference cells provide the reference state A and B values needed during read to determine an array cell threshold state. Two additional reference cells provide the 0 0 state and 0 0.5 state values needed to verify proper programming of an array cell, the 1 1 state being an unprogrammed state. Six sets of the four reference cells are required to provide six different sets of four bit line outputs to six different array cells to provide an eight bit output. Six array cells are utilized in a 3/2 density design to provide an eight bit output because with each array cell storing one of three possible states, instead of two as with a single density design, only six cells are required to store the possible values required to represent eight bits.

The circuitry of Fig. 7 further includes the golden reference cell with a word line connection (MSTRWL) and a bit line connection (GOLBL). The golden bit has a UV-erased floating gate which remains unprogrammed. The reference cells of Fig. 7 are preferably included as core cells on the same integrated circuit as array cells which utilize the reference c lls for program and read so that with

temperature and process variations, variations between the reference cells and array cells remain substantially uniform.

Reference Count Circuit 604

Fig. 8 shows circuitry for the reference count circuit 604 of Fig. 6. To provide a counter, the circuitry of Fig. 8 includes a plurality of shift registers 801-806. To synchronize counting, the VERIFY signal is applied to the CLK input of shifter 801 and through an inverter 810 to the CLKB input of shifter 801. The RDSO0-RDSO3 signals are received and ORed by NOR gate 812 and inverter 814 to provide the DATA input of shifter 801. When a bit is verified to be programmed, one of the RDSO0-RDSO3 signals will be asserted so that on the falling edge of VERIFY, Q and QB of shifter 801 will change states.

The Q and QB outputs of shifter 801 are connected to the CLKB and CLK inputs of shifter 802 respectively. Further, the Q and QB outputs of shifters 802 and 803 are connected to respective CLK and CLKB inputs of shifters 803 and 804 while the QB outputs of shifters 802, 803 and 804 are fed back to their respective DATA inputs. The Q and QB outputs of shifters 802, 803 and 804 form Q0, QB0, Q1, Q10, Q2 and Q20 outputs respectively. The Q1 and Q2 outputs are connected to a NAND gate 816 to the CLK input of shifter 805, while the output of NAND gate 816 is connected through inverter 818 to the CLKB input of shifter 805. The Q and QB outputs of shifter 805 are connected to the CLK and CLKB inputs of shifter 806 while the QB outputs of shifters 805 and 806 are fed back to their respective DATA inputs. The Q and QB outputs of shifters 804 and 805 form Q3, QB3, Q4, and QB4 outputs respectively.

To provide the ROW0-ROW5 and COL0-COL3 output signals, logic circuitry is provided as connected to the Q1-Q4 and QB1-QB4 outputs of shifters 802-806. Logic circuitry 820 is connected as shown to several combinations of the Q0-Q2 and QB0-QB2 outputs to sequence through row bits (ROW0-ROW5), while the column being worked on (COL0-COL3) is updated as controlled by combinations of the Q3, QB3, Q4, and QB4 outputs connected to logic 822.

To reset the shift registers upon entering the program reference mode, shift registers 801, 805 and 806 have resets connected to receive the complement of the PRREF signal through inverter 810. Further, shift registers 802-804 receive the complement of the PRREF signal through NAND gate 824 upon entering the program reference mode. The output of NAND gate 816 is further connected through NAND gate 824 to reset shift registers 802-804 when the column being worked on is updated.

Fig. 9 shows circuitry for the shift registers 801-806 of Fig. 8. The shift register of Fig. 9 includes two latches 902 and 904. A transistor 906 has a current path coupling a DATA input signal to the input of latch 902. Transistor 906 has a gate connected to a CLK input. The input of latch 902 is further connected to ground through transistor 908 which has a gate connected to a RESET input. A transistor 910 has a current path coupling the output of latch 902 to the input of latch 904 as controlled by a CLKB input connected to its gate. The input of latch 904 is further connected to V_{cc} through transistor 912 as controlled by the RESET input. The output of latch 904 provides the Q output of the shifter while the QB output is provided from the output of latch 904 through an inverter 914.

Data Buffer Reference Circuit 606

Fig. 10 shows circuitry for the data buffer reference circuit 606 shown in Fig. 6. The circuitry of Fig. 10 receives the PRREF signal when the program reference mode is entered, the PGM signal from program-verify signal circuit 602 indicates a programming signal is applied, and the COL0-COL3 signals output from the reference count circuit 604 as shown in Fig. 6. The PRREF and PGM signals are connected along with each of the COL0-COL3 signals to inputs of respective NAND gates 1001-1004 to enable one of buffers 1011-1014 when the PRREF, PGM and a respective COL0-COL3 inputs are enabled. Buffers 1011-1014 receive the high voltage VPROG signal from the program-verify signal circuit 602 of Fig. 6 and provide VPROG to a respective reference cell bit line (REFBL0-REFBL3) when its respective buffer is enabled. When VPROG is not applied, the REFBL0-REFBL3 outputs present a high impedance.

Buffers 1011-1014 have identical circuitry, so only the circuitry of buffer 1011 will be described. Buffer 1011 receives a select input signal from the output of NAND gate 1001 at the gate of p-channel transistor 1022 which has a current path coupling VPROG to REFBL1. Thus, when the buffer is not selected, transistor 1022 provides a high impedance output on line REFBL1. An n-channel transistor 1024 is connected between the gate of transistor 1022 and the output of NAND gate 1001 with its gate connected to VPROG to provide protection if VPROG should drop below V_{cc}. Since VPROG has a value significantly higher than V_{cc}, to prevent feedback of VPROG, an n-channel transistor 1026 is connected between the gate of transistor 1022 and the output of NAND gate 1001 which has a gate connected to V_{cc}. Another p-channel transistor

1028 couples VPROG to the input of transistor 1022 to assure transistor 1022 remains off when buffer 1011 is deselected. Transistor 1028 has a gate controlled by an inverter 1030, inverter 1030 having an input connected to the input of transistor 1022 and power supplied by VPROG. As shown in Fig. 10, and in subsequent drawings, an angled line from the drain to source of a transistor, such as on transistor 1022, indicates a p-channel transistor, while no line indicates an n-channel transistor.

Sense Bias Circuit 608

Fig. 11 shows circuitry for the sense bias circuit 608 shown in Fig. 6. The circuitry of Fig. 11 receives the PRREF signal when the program reference mode is entered and the ROW0-ROW5 signals output from the reference count circuit 604 shown in Fig. 6. The PRREF signal is connected along with each of the ROW0-ROW5 signals to inputs of respective NAND gates 1101-1106 to enable one of buffers 1111-1116 when the PRREF signal and a respective ROW0-ROW5 input is enabled. Buffers 1111-1116 alternately receive the program and verify voltages over VPX from the program-verify signal circuit 602 of Fig. 6 and couple VPX to a respective reference cell word line (REFWL0-REFWL5) when its respective buffer is enabled. A word line not selected is typically grounded.

The circuitry of Fig. 11 further receives a READ signal when a read or verify mode is entered to determine a state of an array cell. The PGM signal is also received through inverter 1108 indicating that the VPX signal is not being applied to program or erase an array cell. The PRREF signal is further received through inverter 1109 to indicate that verify of a reference cell is not occurring. The READ signal and the outputs of inverters 1108 and 1109 are applied to the input of NAND gate 1110. During read of an array cell, buffers 1111-1116 receive a read or verify voltage over VPX and provide the VPX signal to all the reference cell word lines (REFWL0-REFWL5).

Buffers 1111-1116 have identical circuitry, so only the circuitry of buffer 1111 will be described. Buffer 1111 receives a select input signal from the output of NAND gates 1101 and 1110 at the inputs of NAND gate 1118. The output of NAND gate 1118 is provided through inverter 1120 to the input of an inverter formed by transistors 1122 and 1124. The output of inverter 1122,1124 provides the REFWL0 signal. Pull up transistor 1122 couples the VPX signal to the REFWL0 output when the output inverter 1120 is low. Pull down transistor 1124 couples the REFWL0 output to ground when the output of inverter 1120 is high. A transistor 1126 has a curr nt path connected between VPX and the input of inverter 1122,1124 and has a gate connected to the REFWL0 output to assure transistor 1122 is off when buffer 1111 is deselected. Since VPX has a value significantly higher than V_{cc} during program, to prevent feedback, an n-channel transistor 1128 is connected between the input of inverter 1122,1124 and the output of inverter 1120 and has a gate connected to V_{cc}.

Reference Bias Circuit 610

Fig. 12 shows circuitry for the reference bias circuit 610 shown in Fig. 6. The circuitry of Fig. 12 receives COL0-COL3 signals output from the reference count circuit 604 shown in Fig. 6. The COL0-COL3 signals are connected to the gates of p-channel transistors 1201-1204 through inverters 1211-1214 to couple a resistor ratio to the gate of the golden reference MSTRWL as selected by the COL0-COL3 signals. The resistor ratios are formed by coupling the current paths of transistors 1201-1204 respectively between successive ones of resistors 1221-1225 and MSTRWL.

As discussed previously, the circuitry of Fig. 12 enables the reference cells to be verified as properly programmed utilizing the bias gate method. The bias gate method couples a resistor ratio to the gate of the golden reference and compares the golden reference output with an output of a reference cell being programmed to determine if the floating gate of the reference cell is charged to a proper threshold level. This method utilizes the fact that the golden bit will be saturated according to the MOS transistor saturation equation $I_D = K(V_{GS} - V_t)^2$, so that reducing the gate voltage V_{GS} by a fixed amount using a resister ratio will provide the same current as a reference cell that has been programmed to a desired threshold value v_t.

For example, utilizing the bias gate method, if a .55V differential between thresholds is required to stay between a maximum range of programmable threshold voltages of 4.0V to 1.8V, four reference thresholds will be programmed with a 3/2 density array, as shown in Fig. 2, at 3.45V, 2.90V, 2.35V and 1.80V. To program a first reference to a level of 3.45V, a resistor ratio is chosen to bias the gate of the golden reference at V_{cc}-.55V. Different resistor ratios are subsequently selected to bias the gate of the golden reference to program the remaining reference cells. Note, as discussed previously, because with the bias gate method, as V_{cc} is varied, the thresholds programmed will vary with respect to each other, programming is preferably done at test tim by the manufacturer to maintain V_{cc} within tight tolerances. Similarly, to assure the thresholds remain constant with respect to one another, the manufacturer preferably controls temperature within tight tolerances.

Reference Sense Circuit 612

Fig. 13 shows circuitry for the reference sense circuit 612 shown in Fig. 6. The circuitry of Fig. 12 provides an enable signal (REFSEN0-REFSEN4) to enable cascode preamplifiers of circuitry 614 and a sense amplifier of circuitry 616 to verify if the currently selected reference is properly programmed. The REFSEN0-REFSEN4 signal is provided when VERIFY is asserted and the PRREF signal is received. To conserve power, the column signal (COL0-COL3) from reference count circuit 604 is utilized to select only the necessary REFSEN0-REFSEN4 outputs to enable the cascode preamplifiers and sense amplifiers necessary to verify if the selected reference cell is properly programmed.

The circuitry of Fig. 12 receives the VERIFY and PRREF signals at the inputs of NAND gate 1302. The output of NAND gate 1302 is connected to the inputs of NOR gates 1311-1314 along with respective ones of COL0-COL3 signals as provided through inverters 1321-1324. The outputs of NOR gates 1311-1314 provide the REFSEN0-REFSEN3 output signals. The outputs of NOR gates 1311-1314 are further ORed by NOR gate 1326 and inverter 1328 to provide a REFSEN4 signal which is provided to enable the cascode preamplifier connected to the golden reference when one of the REFSEN0-REFSEN3 signals are enabled.

Cascode Preamplifiers 614

Fig. 14 shows circuitry for one of the cascode preamplifiers utilized in the cascode preamplifiers 614 shown in Fig. 6. The cascode preamplifiers 614 of Fig. 6 include five cascode preamplifiers as shown in Fig. 14. Four cascode preamplifiers are provided to receive each bit line output REFBL0-REFBL3 and an additional cascode preamplifier receives the GOLBL output. The cascode preamplifiers convert a current from the bit line received to an output voltage SAREF1-SAREF4 during the verify process. Each cascode preamplifier receives a respective enable signal REFSEN0-REFSEN4 from reference sense circuit 612 to enable the verify process as described previously.

As shown, the circuit of Fig. 14 receives a REFBLi signal representative of a particular bit line signal (REFBL0-REFBL3 or GOLBL) and a REFSENi signal representative of a REFSEN0-REFSEN4 enabling signal. The output, SAREFi, is representative of the particular SAREF0-SAREF4 signal output. The cascode amplifier is provided in the circuit of Fig. 14 by a cascode transistor 1402 having a drain connected to the SAREFi output.

The preamplifier is enabled by the complement of REFSENi provided through an inverter 1408 to the gate of an enabling transistor 1404. The enabling transistor 1404 is connected in series with an n-channel level shifting transistor 1418 and a p-channel load transistor 1406 between V_{cc} and the SAREFi output. To provide bias for cascode 1402, the complement of REFSENi is further provided through inverter 1408 to the gate of a switching transistor 1410. Transistor 1410 is connected in series with a feedback load transistor 1420 between V_{cc} and the gate of cascode 1402. To disable the preamplifier, an n-channel switching transistor 1412 is provided with a gate connected to the output of inverter 1408 to couple the gate of cascode 1402 to ground when the complement of REFSENi is not provided.

The REFBLi signal is provided through a transistor 1414 to the source of cascode 1402 to be amplified at the SAREFi output. The gate of transistor 1414 is enabled by REFSENi when the preamplifier is enabled. Further biasing for cascode 1402 is provided by feedback from the source of cascode 1402 by transistor 1416. Transistor 1416 has a gate connected to the source of transistor 1402, a drain connected to the gate of transistor 1402 and a source connected to ground.

Sense Amplifiers 616

Fig. 15 shows circuitry for one of the sense amplifiers utilized in the sense amplifiers 616 shown in Fig. 6. Sense amplifiers 616 of Fig. 6 include four sense amplifiers as shown in Fig. 15. The four sense amplifiers are provided to compare an enabled reference cell output voltage (SAREF0-SAREF3) to the golden reference output voltage (SAREF4) The sense amplifier output signals (RDSO0-RESO3) indicate if a cell being programmed is fully programmed.

As shown, the circuit of Fig. 15 receives a SAREFi signal representative of a particular cascode preamplifier output (SAREF0-SAREF3) from a selected reference cell and a SAREF4 signal from the cascode preamplifier connected to the golden reference. The circuit of Fig. 15 further receives a REFSENi signal representative of a REFSEN0-REFSEN3 enabling signal and outputs a RDSOi signal representative of the particular RDSO1-RDSO3 output.

The sense amplifier of Fig. 15 is a differential amplifier 1500 which is enabled by the REFSENi signal. The sense amplifier compares the SAREFi and SAREFGB signals and outputs the RDSOi signal when the value of SAREFi exceeds SAREF4.

Although the invention has been described above with particularity, this was merely to teach one of ordinary skill in the art how to make and us the invention. Many modifications will fall within the scope of the invention, as that scope is defined by

the following claims.

Claims

1. A reference for determining a state in a plurality of possible states stored by an array cell in a memory array, the reference comprising:
   a programmable reference cell having a floating gate which stores an electrical charge programmed to a predetermined level.

2. The reference of Claim 1 wherein the reference cell and the array cell are biased substantially the same.

3. The reference of Claim 1 wherein a select voltage applied to the gate of the array cell to determine the state stored by the array cell is also applied to the gate of the reference cell.

4. The reference of Claim 3 wherein when the select voltage is varied a working margin between the plurality of possible array cell states does not substantially vary.

5. The reference of Claim 1 wherein the reference cell and the array cell are included as core cells on a single integrated circuit so that the reference cell and the array cell have substantially the same rate of thermal expansion.

6. A memory comprising:
   an array cell having a gate, an output, and an array threshold value set to one of n array threshold values;
   n-1 programmable reference cells, each reference cell having a gate, an output and a floating gate which stores an electrical charge to allow a reference threshold value to be programmed, each respective reference cell having its reference threshold value programmed between two different successive ones of the n array threshold values;
   a selector for supplying a select voltage to the gate of the array cell and the gates of the reference cells; and
   a comparison means coupled to receive the array cell output and the reference cell outputs, the comparison means providing a signal indicating which of the n array threshold values is held by the array cell.

7. The m mory of Claim 6 wherein the programmable reference cells and the array cell are biased substantially the same.

8. The memory of Claim 6 wherein the select voltage applied to the gate of the array cell has substantially the same value as the select voltage applied to the gate of the programmable reference cells.

9. The memory of Claim 6 wherein the programmable reference cells and the array cell are included as core cells on a single integrated circuit so that the programmable reference cells and the array cell have substantially the same rate of thermal expansion.

10. The memory of Claim 6 wherein when a value of the select voltage is varied, a working margin between the array cell output and the reference cell outputs remains constant.

11. A memory comprising:
   an array cell having a gate and a floating gate which stores an electrical charge to allow an array threshold value to be programmed;
   n program reference cells, each program reference cell having a gate and a floating gate which stores an electrical charge to allow a program reference threshold value to be programmed;
   n-1 read reference cells, each read reference cell having a gate and a floating gate which stores an electrical charge to allow a read reference threshold value to be programmed;
   a reference program-verify means for alternately applying program and reference verify voltages to the n program reference cells to program the n program reference cells to different n program reference threshold values and for alternately applying the program and reference verify voltages to the n-1 read reference cells to program the read reference threshold value for each successive read reference cell between two successive ones of the program reference threshold values;
   an array program-verify means for alternately applying program and array verify voltages to the floating gate of the array cell until the array threshold value is programmed to be equal to the program reference threshold value of a given one of the n program reference cells;
   a selector for supplying a select voltage to the gate of the array cell and the gates of the read reference cells to obtain an array cell output and a read reference cell output from each of the read reference cells; and
   a comparison means coupled to receive the array cell output and the read reference cell outputs, the comparison means providing a signal indicating the given one of the n program reference cells used to program the

array cell.

12. The memory of Claim 11 wherein the reference verify voltage has a value which varies significantly less than the array verify voltage.

13. The memory of Claim 11 wherein when the array cell is being read or programmed, the read reference cells, the program reference cells and the array cell are biased substantially the same.

14. The memory of Claim 11 wherein the select voltage applied to the gate of the array cell has substantially the same value as the select voltage applied to the gate of the read reference cells.

15. The memory of Claim 11 wherein the program reference cells, the read reference cells and the array cell are included as core cells on a single integrated circuit so that the program reference cells, the read reference cells and the array cell have substantially the same rate of thermal expansion.

16. The memory of Claim 11 wherein when a value of the select voltage is varied a working margin between outputs of the program reference cells, the read reference cell outputs and the array cell output remains constant.

17. An apparatus for programming a plurality of reference cells used to read a threshold voltage of an array cell, each reference cell in the plurality of reference cells having a REFWL connection at its gate and a REFBL connection at its drain, the apparatus comprising:

a reference count circuit for sequentially selecting a particular reference cell in the plurality of reference cells, the reference count circuit indicating the particular reference cell being selected by outputting a COL signal and a ROW signal and sequencing to a next sequential reference cell when a RDSO signal is received;

a program-verify signal circuit for supplying a program-verify voltage for applying to the gate of the particular reference cell to alternately program the particular reference cell and verify if the particular referenc cell is fully programmed, and for supplying a program voltage for applying to the drain of the particular reference cell during programming, and for supplying a verify signal during verification;

a sense bias circuit for receiving the ROW signal and th program-verify voltage and coupling the program-verify voltage to the REFWL connection of the particular reference cell as controlled by the ROW signal;

a data buffer reference circuit for receiving the COL signal and the program voltage and coupling the program voltage to the REFBL connection of the particular reference cell as controlled by the COL signal;

a golden bit cell having a MSTRWL connection at its gate and a GOLBL connection at its drain;

a reference bias circuit having a plurality of resistance ratios, each resistance ratio being coupled between a read voltage and the MSTRWL connection as controlled by the COL signal; and

a comparison circuit for receiving the COL signal, the verify signal, a GOLBL signal from the GOLBL connection and a REFBL signal from the REFBL connection of the particular reference cell, and comparing the GOLBL signal to the REFBL signal during application of the verify signal and outputting the RDSO signal when the GOLBL signal is substantially equal to voltage of the REFBL signal.

18. The apparatus of Claim 17 wherein the plurality of reference cells are also utilized to program a threshold voltage of an array cell.

19. The apparatus of Claim 17 wherein the comparison circuit comprises:

a reference sense circuit for receiving the COL signal and the verify signal and outputting a REFSEN signal indicative of the COL signal when the verify signal is applied;

a first preamplifier receiving the REFSEN signal, and the REFBL signal and outputting a SAREF voltage indicative of the REFBL signal when the REFSEN signal is applied;

a second preamplifier receiving the REFSEN signal, and the GOLBL signal and outputting a SAREFGB voltage indicative of the GOLBL signal when the REFSEN signal is applied;

a sense amplifier receiving the SAREF voltage and the SAREFGB voltage and outputting the RDSO signal when the SAREF voltage and the SAREFGB voltage are substantially equal.

20. A method of programming n reference cells comprising the successive steps of:

(a) selecting a first of the n reference cells as a selected reference cell and a first of n resistor ratios as a selected resistor ratio;

(b) coupling th selected resistor ratio to a gate of a golden bit cell;

(c) applying a program voltage to increase charge stored on a floating gate of the selected reference cell;
(d) applying a reference verify voltage to the gate of the selected reference cell and through the selected resistor ratio to the gate of the golden bit to create a selected reference cell output and a golden bit cell output;
(e) comparing the selected reference cell output and the golden bit cell output and proceeding to step (c) if the selected reference cell output is not substantially equal to the golden bit cell output;
(f) selecting a next successive reference cell in the n reference cells as the selected reference cell and a next successive resistor ratio in the n resistor ratios as the selected resistor ratio and proceeding to step (b) if the n^{th} reference cell in the n reference cells has not been previously selected.

21. A method of programming an array cell comprising the steps of:
(a) selecting a reference cell in a plurality of reference cells having a floating gate storing a charge representative of a value to which the array cell is to be programmed;
(b) applying a program voltage to increase charge stored on a floating gate of the array cell;
(c) applying an array verify voltage to a gate of a reference cell and a gate of the array cell to create a reference cell output and an array cell output; and
(d) comparing the reference cell output and the array cell output and proceeding to step (b) if the array cell output is not substantially equal to the reference cell output.

22. The method of Claim 21 wherein the reference cell is programmed according to the method of Claim 20.

23. The method of Claim 22 wherein the reference verify voltage has a value which varies significantly less than the array verify voltage.

24. A method of reading an array cell which stores one of n array threshold values comprising the steps of:
applying a read voltage to a gate of an array cell to generate an array cell output;
applying the read voltage to gates of a plurality of reference cells to generate respective reference cell outputs, each reference cell having a floating gate for storing a different electrical charge to allow a reference threshold value to be programmed, each successive reference cell having its reference threshold value programmed between two different successive ones of the n array threshold values; and
comparing the array cell output and the reference cell outputs and providing a signal indicating which of the n array threshold values is held by the array cell.

25. The programmable reference of Claim 1 wherein the read voltage applied to the gate of the array cell has substantially the same value as the select voltage applied to the gates of the reference cells.

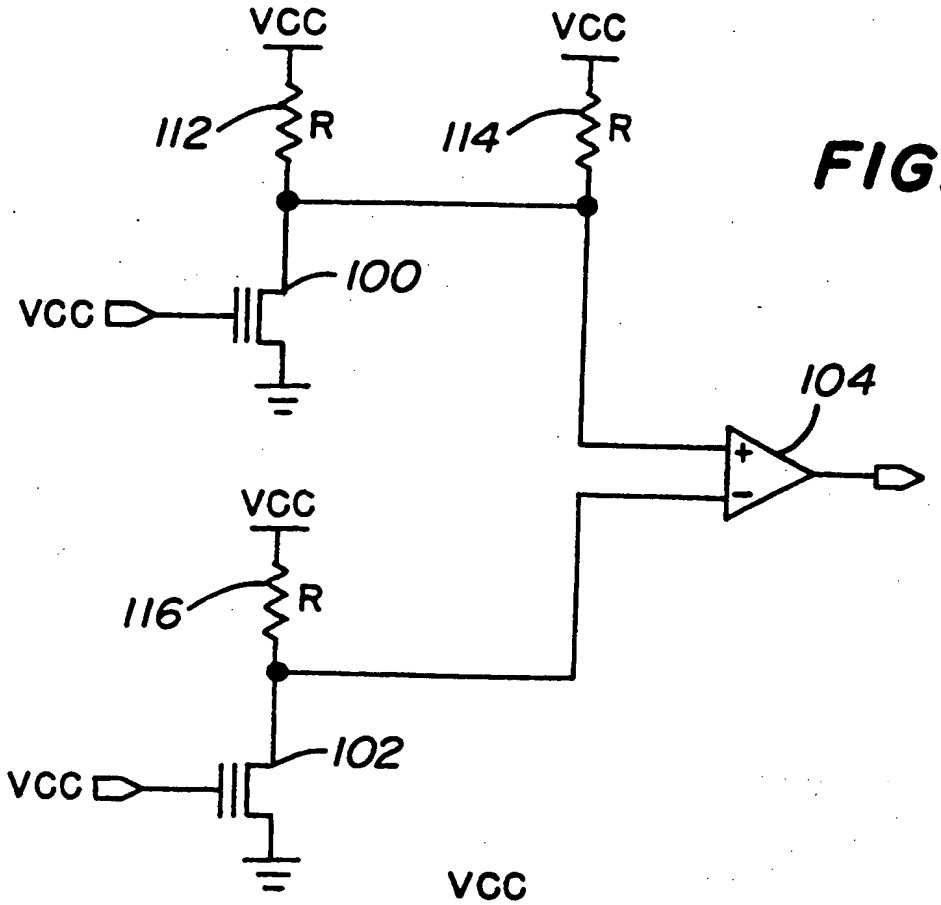

VCC
VCC
112
R
114
R
100
VCC
104
VCC
116
R
102
VCC

FIG. 1

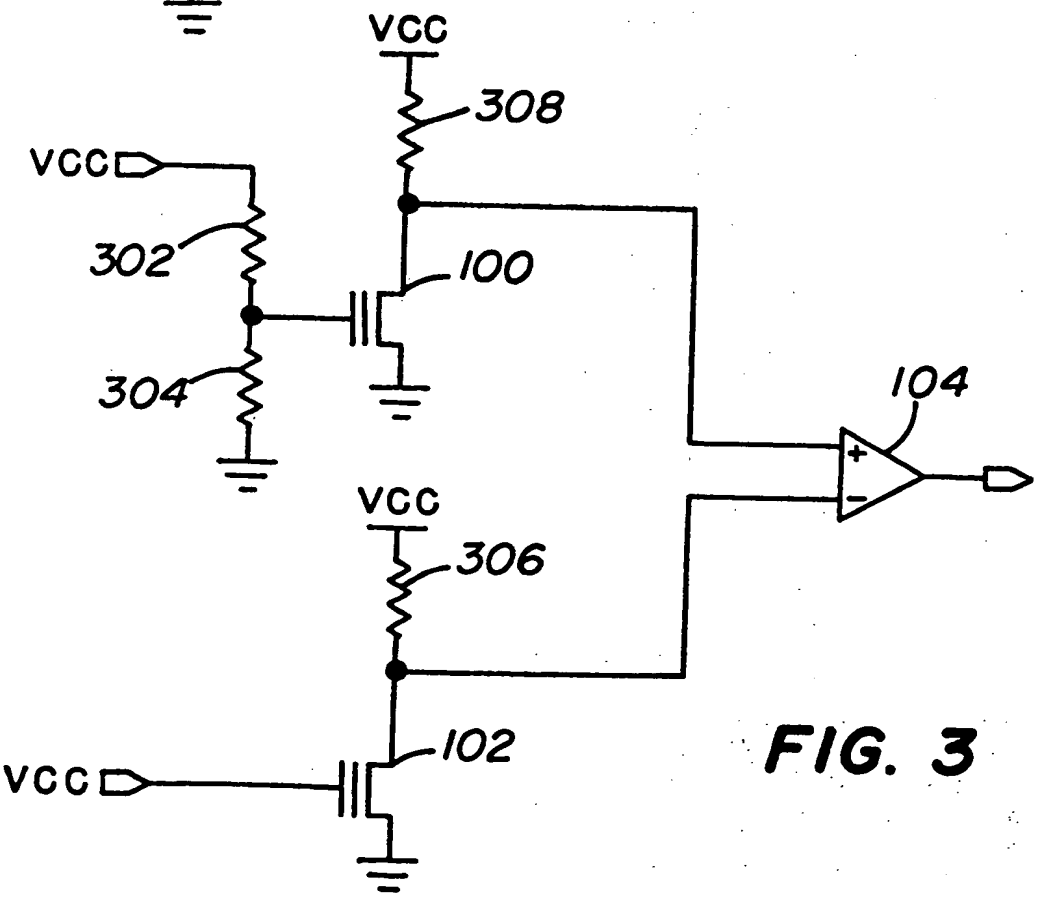
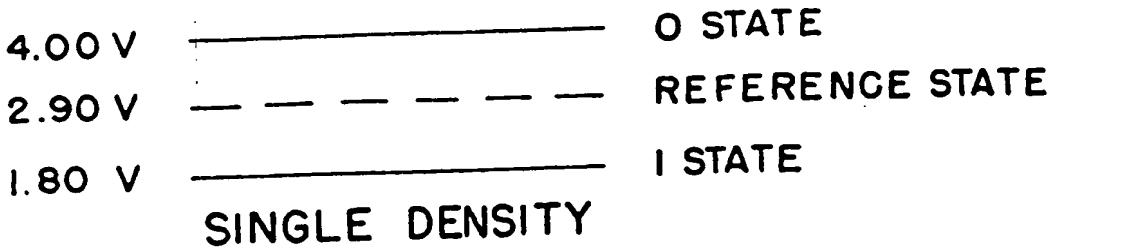
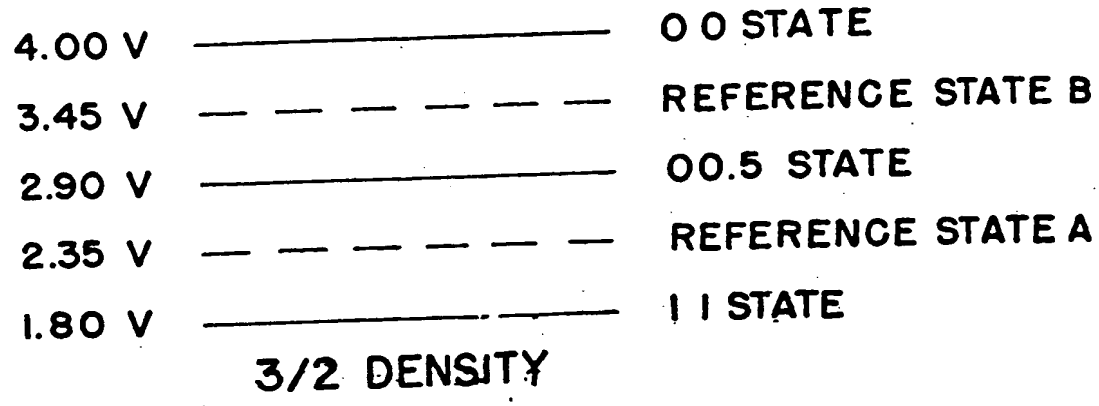

VCC
308
VCC
302
100
304
104
VCC
306
102
VCC

FIG. 3


4.00 V
2.90 V
1.80 V
0 STATE
REFERENCE STATE
1 STATE
SINGLE DENSITY


4.00 V
3.45 V
2.90 V
2.35 V
1.80 V
0 0 STATE
REFERENCE STATE B
00.5 STATE
REFERENCE STATE A
1 1 STATE
3/2 DENSITY

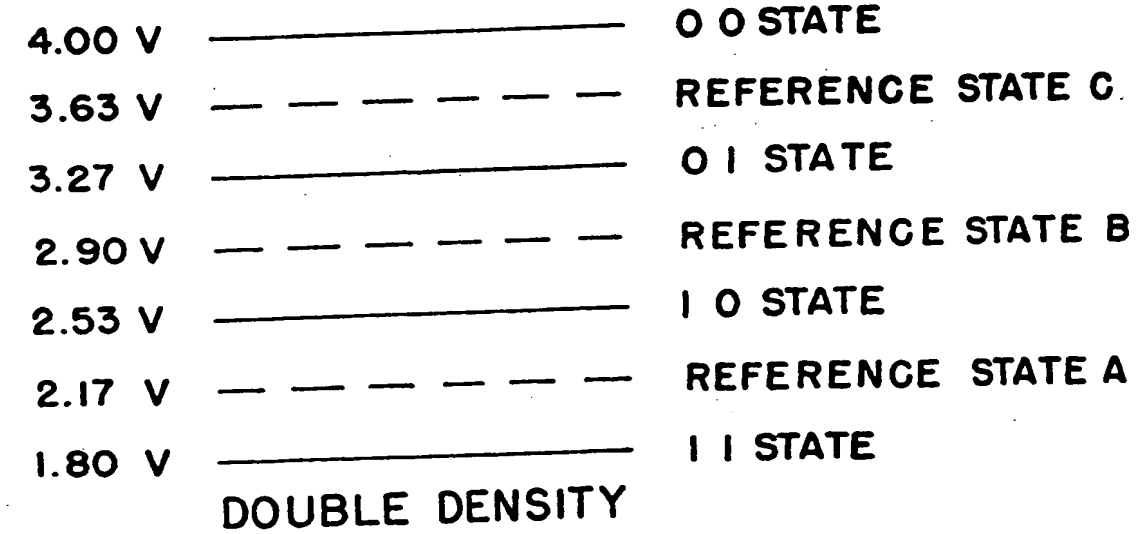

4.00 V
3.63 V
3.27 V
2.90 V
2.53 V
2.17 V
1.80 V
0 0 STATE
REFERENCE STATE C
0 1 STATE
REFERENCE STATE B
1 0 STATE
REFERENCE STATE A
1 1 STATE
DOUBLE DENSITY

FIG 2

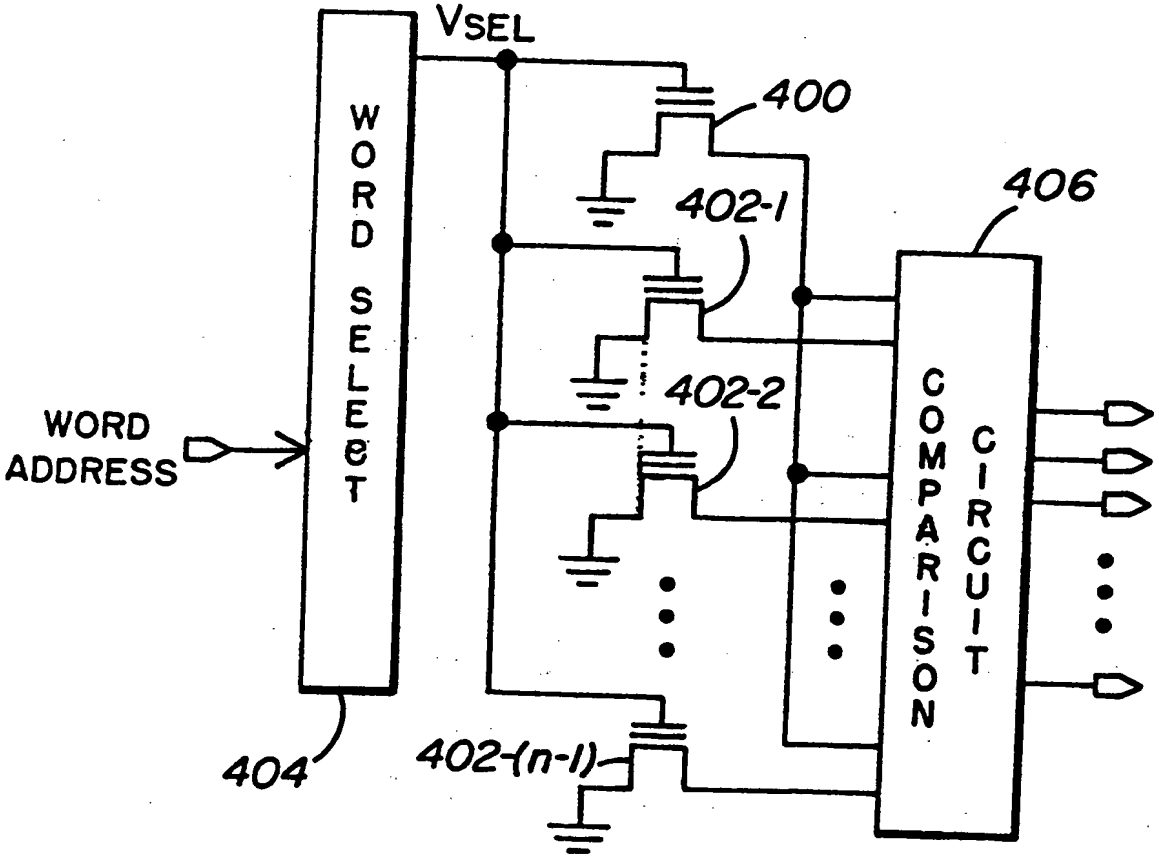

VSEL
400
402-1
406
WORD SELECT
WORD ADDRESS
402-2
COMPARISON CIRCUIT
404
402-(n-1)

FIG. 4

FIG. 5

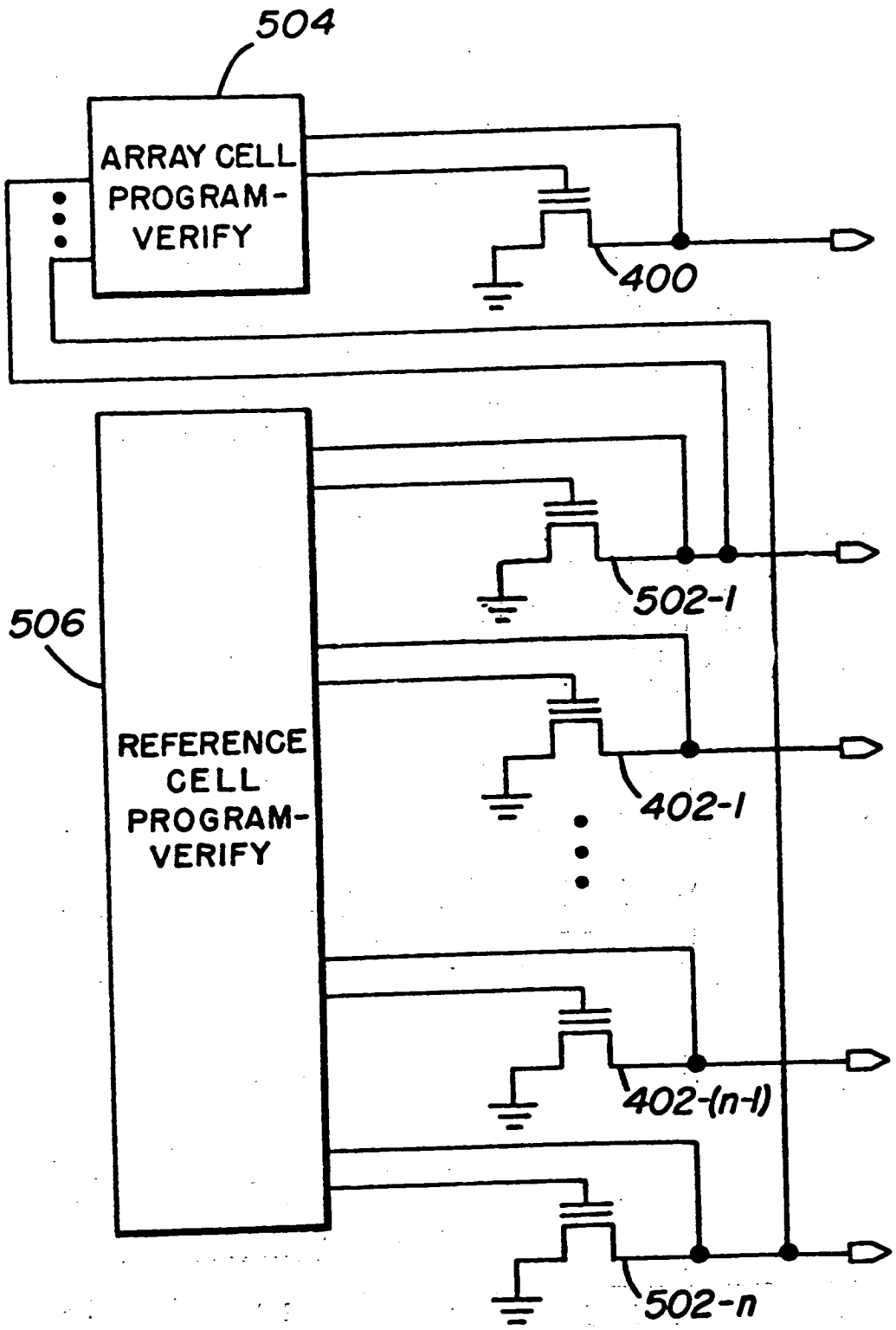

504
ARRAY CELL PROGRAM-VERIFY
400
502-1
506
REFERENCE CELL PROGRAM-VERIFY
402-1
402-(n-1)
502-n

FIG. 6
PART A

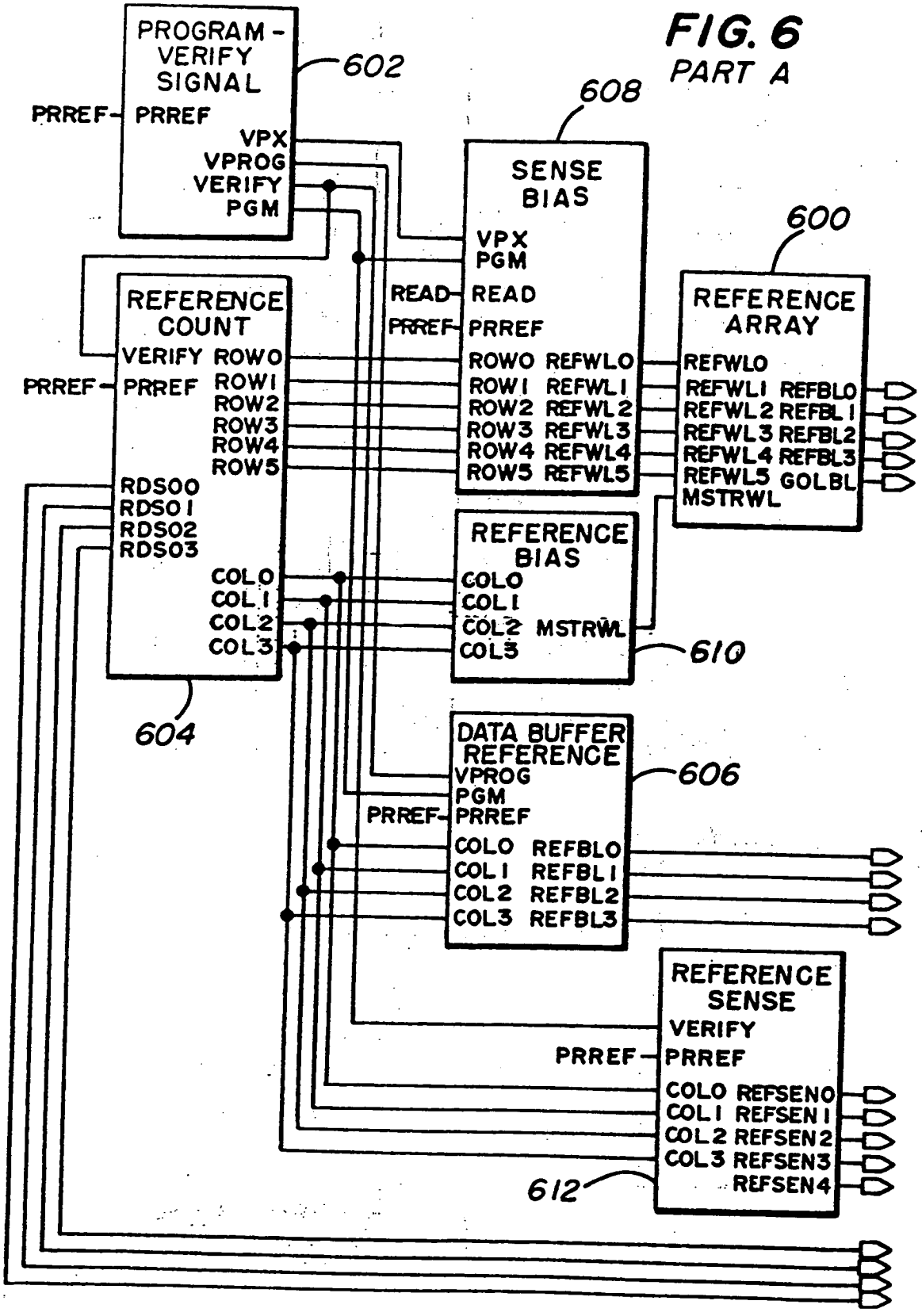
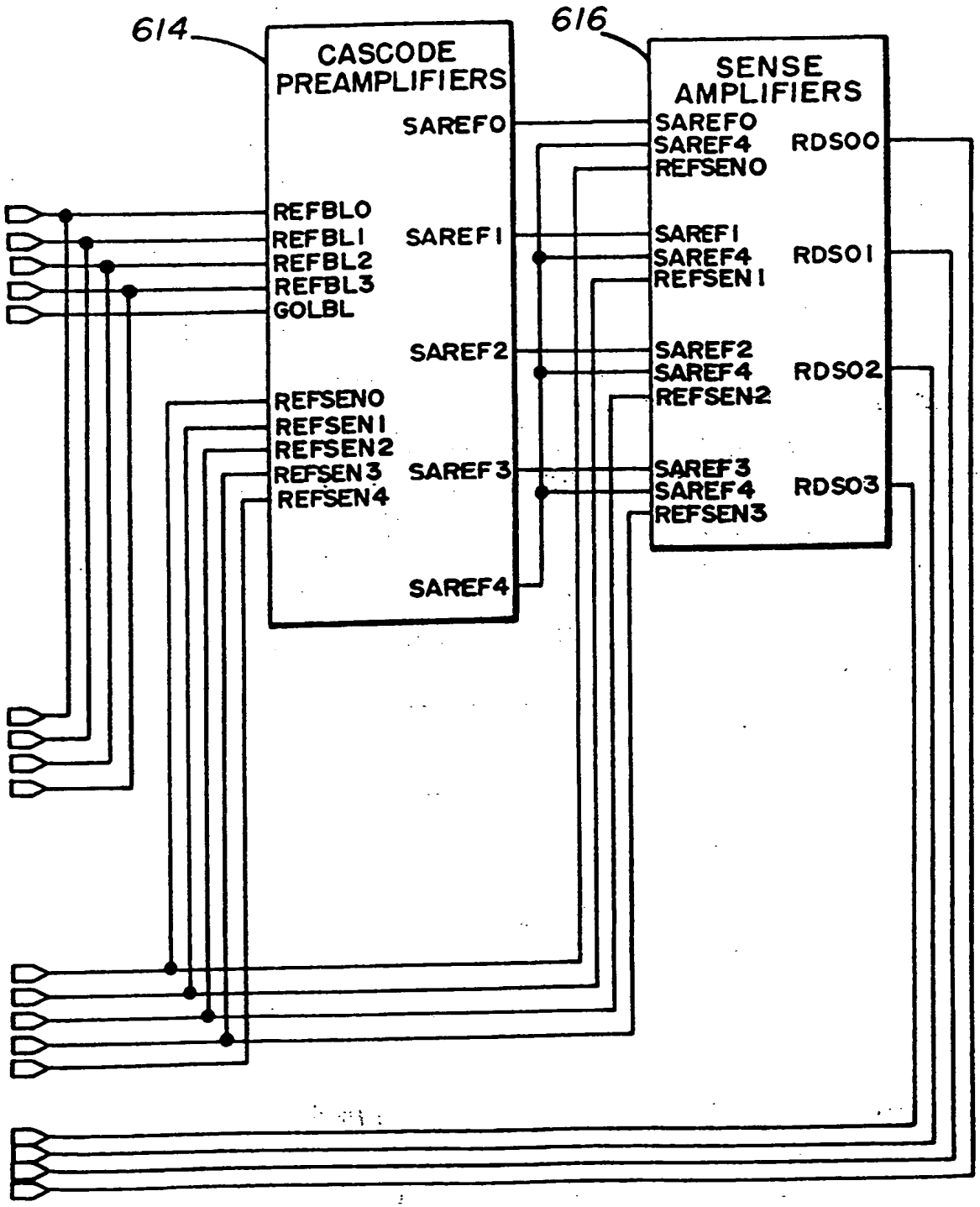

PROGRAM - VERIFY SIGNAL
602
PRREF
PRREF
VPX
VPROG
VERIFY
PGM
608
SENSE BIAS
VPX
PGM
READ
READ
PRREF
PRREF
ROWO REFWLO
ROW1 REFWL1
ROW2 REFWL2
ROW3 REFWL3
ROW4 REFWL4
ROW5 REFWL5
600
REFERENCE ARRAY
REFWLO
REFWL1 REFBLO
REFWL2 REFBL1
REFWL3 REFBL2
REFWL4 REFBL3
REFWL5 GOLBL
MSTRWL
REFERENCE COUNT
VERIFY ROWO
PRREF PRREF
ROW1
ROW2
ROW3
ROW4
ROW5
RDS00
RDS01
RDS02
RDS03
COLO
COL1
COL2
COL3
604
REFERENCE BIAS
COLO
COL1
COL2 MSTRWL
COL3
610
DATA BUFFER REFERENCE
606
VPROG
PGM
PRREF
PRREF
COLO REFBLO
COL1 REFBL1
COL2 REFBL2
COL3 REFBL3
REFERENCE SENSE
VERIFY
PRREF
PRREF
COLO REFSEN0
COL1 REFSEN1
COL2 REFSEN2
COL3 REFSEN3
REFSEN4
612

FIG. 6
PART B


614
CASCODE PREAMPLIFIERS
SAREF0
REFBL0
REFBL1
REFBL2
REFBL3
GOLBL
SAREF1
SAREF2
REFSEN0
REFSEN1
REFSEN2
REFSEN3
REFSEN4
SAREF3
SAREF4
616
SENSE AMPLIFIERS
SAREF0
SAREF4
REFSEN0
RDS00
SAREF1
SAREF4
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SAREF3
SAREF4
REFSEN3
RDS03

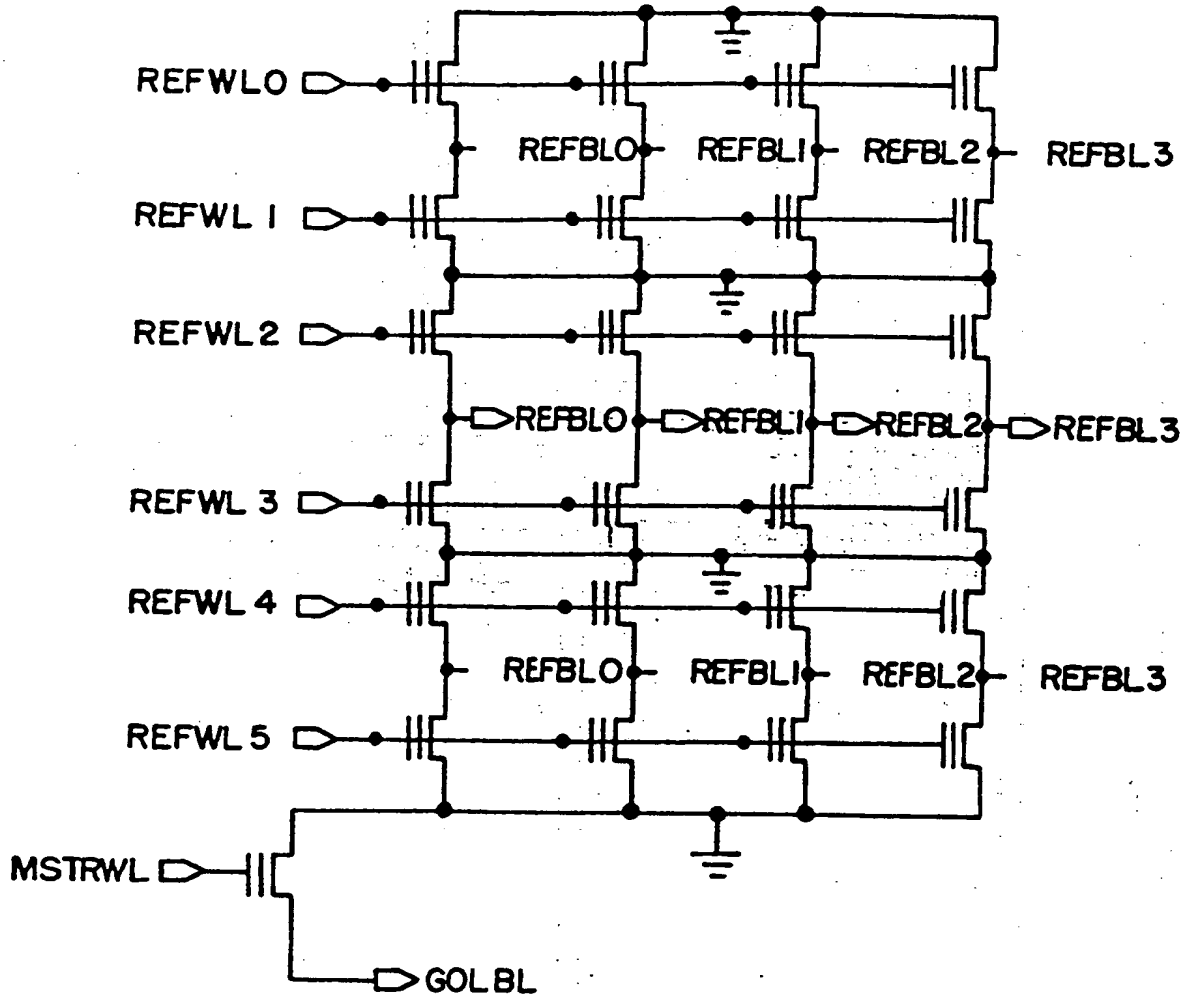

REFWL0
REFBL0
REFBL1
REFBL2
REFBL3
REFWL 1
REFWL2
REFBL0
REFBL1
REFBL2
REFBL3
REFWL 3
REFWL 4
REFBL0
REFBL1
REFBL2
REFBL3
REFWL 5
MSTRWL
GOLBL

FIG. 7

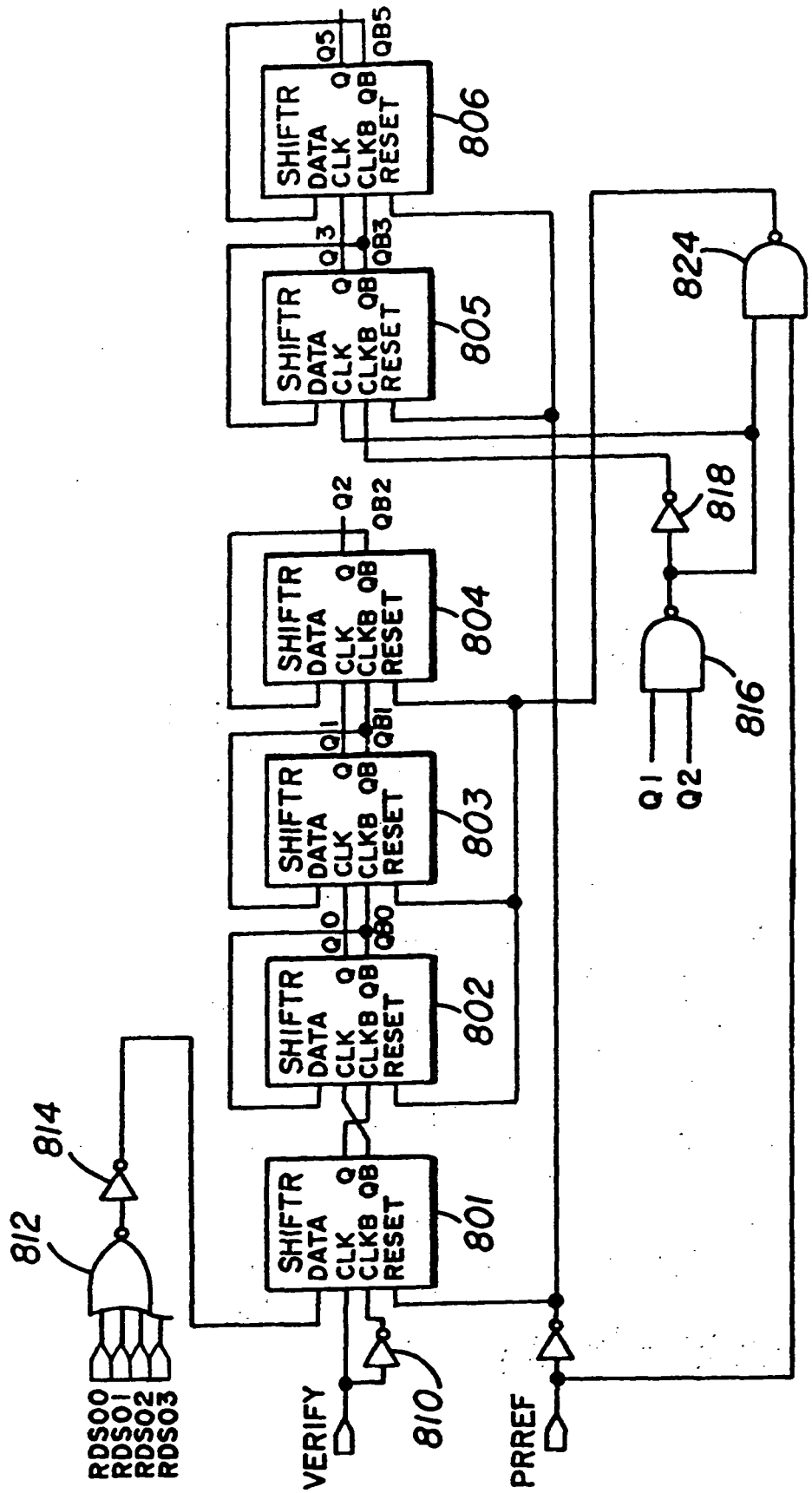

SHIFTR
DATA
CLK
CLKB
RESET
Q
QB
801
802
803
804
805
806
Q0
QB0
Q1
QB1
Q2
QB2
Q3
QB3
Q5
QB5
RDS00
RDS01
RDS02
RDS03
812
814
VERIFY
810
PRREF
816
818
824
Q1
Q2

FIG. 8
PART A

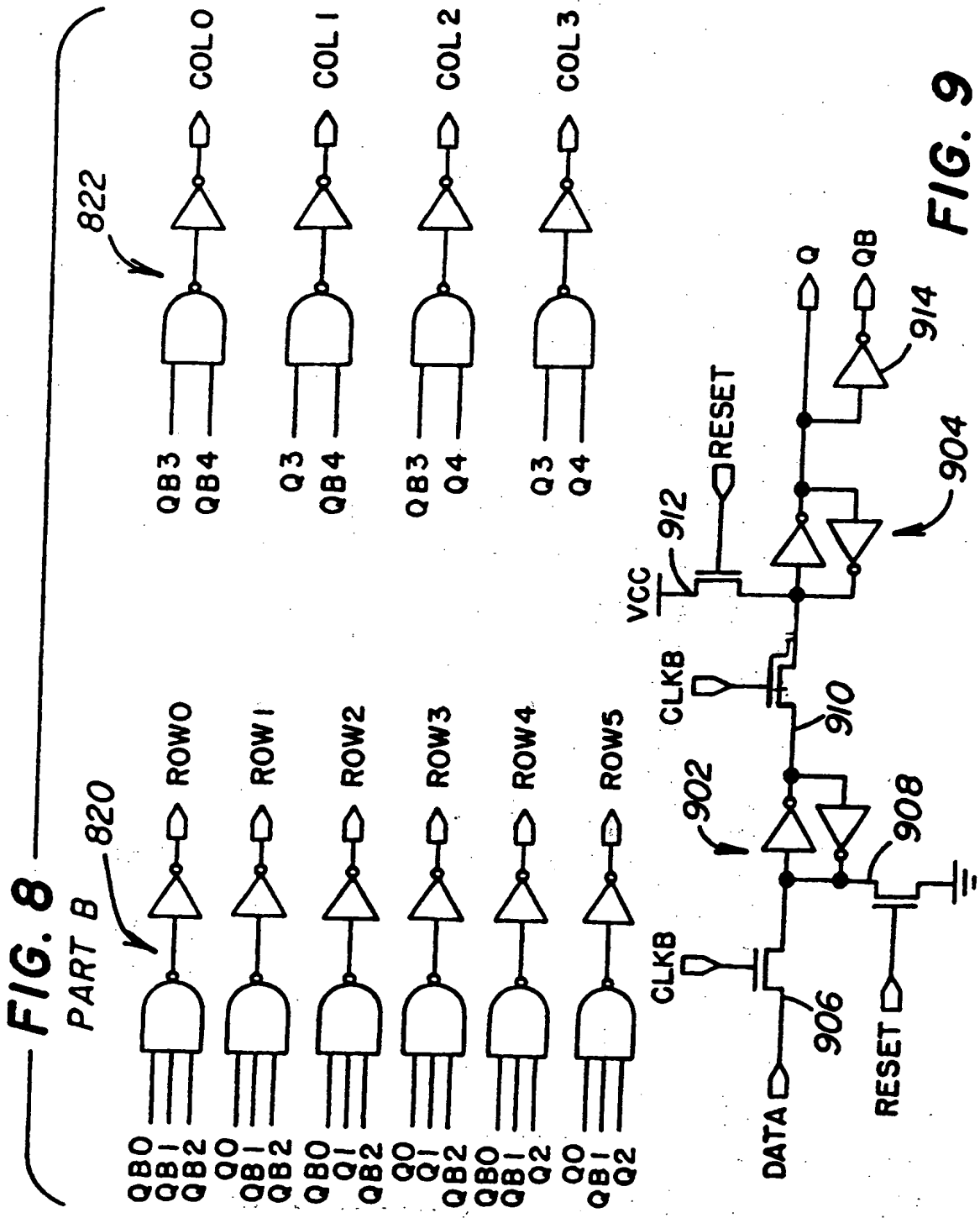
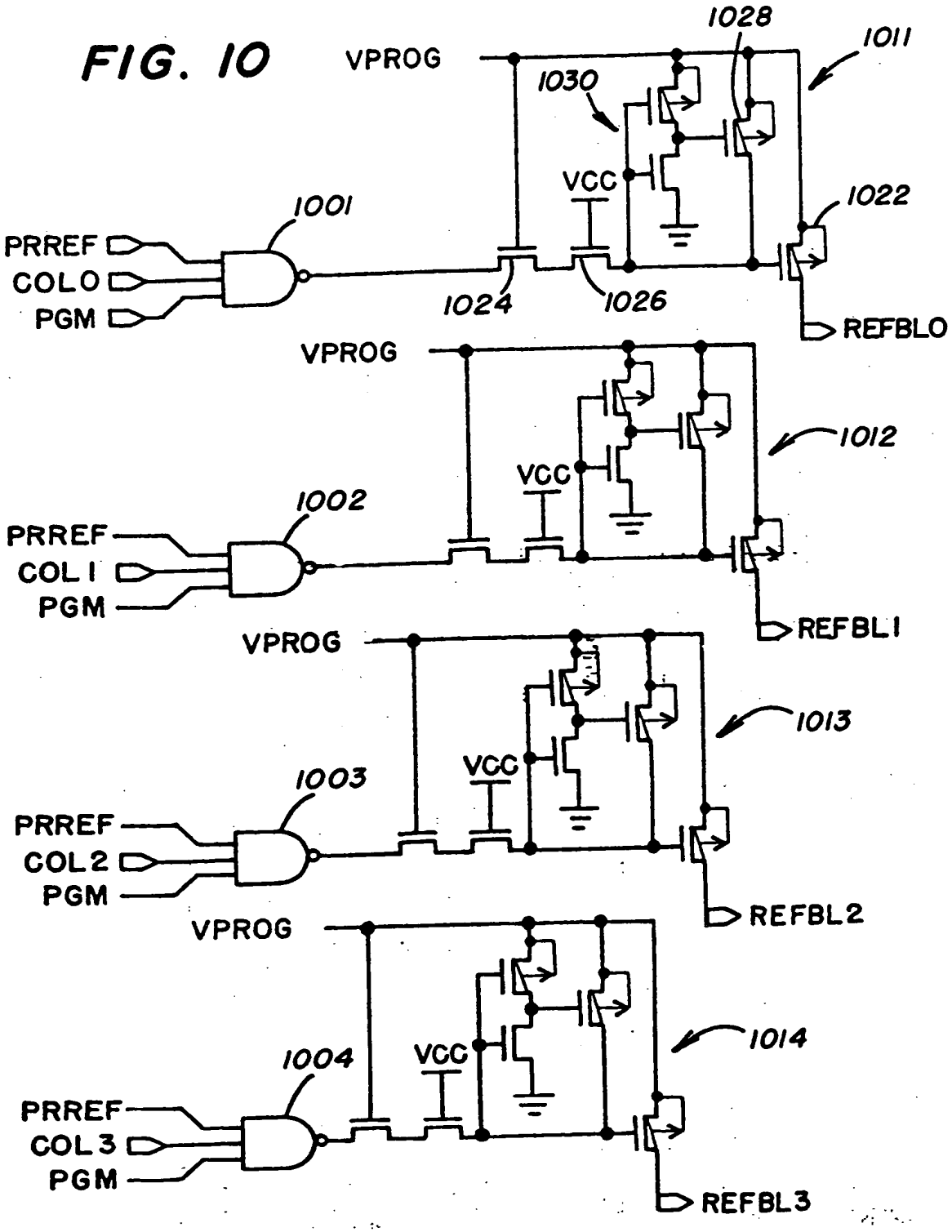


FIG. 8
PART B
820
822
ROW0
ROW1
ROW2
ROW3
ROW4
ROW5
QB0 QB1 QB2
Q0 QB1 QB2
QB0 Q1 QB2
Q0 Q1 QB2
QB0 QB1 Q2
Q0 QB1 Q2
COL0
COL1
COL2
COL3
QB3 QB4
Q3 QB4
QB3 Q4
Q3 Q4
FIG. 9
VCC
912
RESET
CLKB
910
902
908
CLKB
906
DATA
RESET
904
Q
QB
914

FIG. 10


VPROG
1028
1011
1030
VCC
1022
1001
PRREF
COL0
PGM
1024
1026
REFBL0
VPROG
1012
VCC
1002
PRREF
COL1
PGM
REFBL1
VPROG
1013
VCC
1003
PRREF
COL2
PGM
REFBL2
VPROG
1014
VCC
1004
PRREF
COL3
PGM
REFBL3

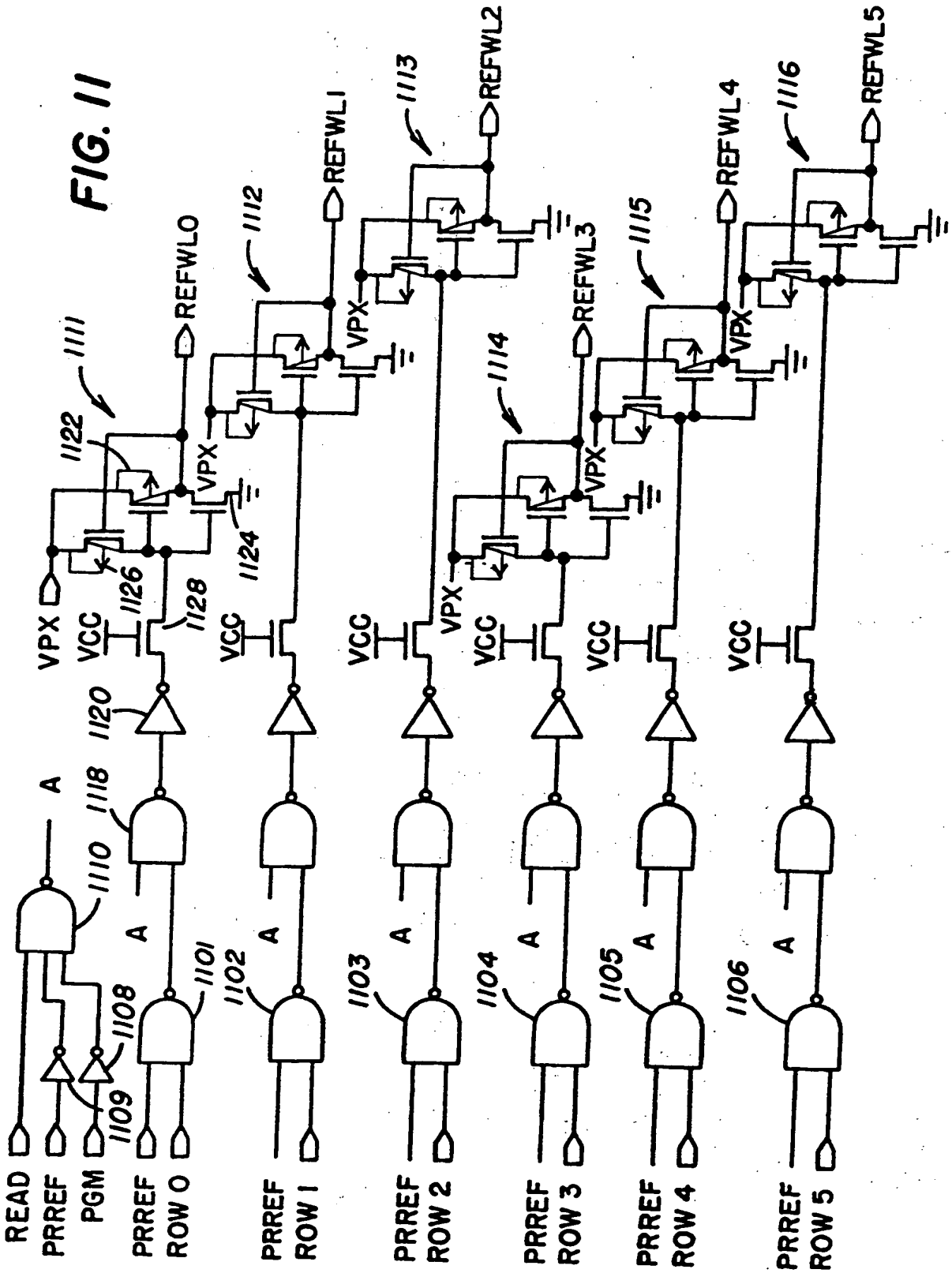

READ
PRREF
PGM
PRREF ROW 0
PRREF ROW 1
PRREF ROW 2
PRREF ROW 3
PRREF ROW 4
PRREF ROW 5
A
VPX
VCC
REFWL0
REFWL1
REFWL2
REFWL3
REFWL4
REFWL5
1101
1102
1103
1104
1105
1106
1108
1109
1110
1111
1112
1113
1114
1115
1116
1118
1120
1122
1124
1126
1128

FIG. 11

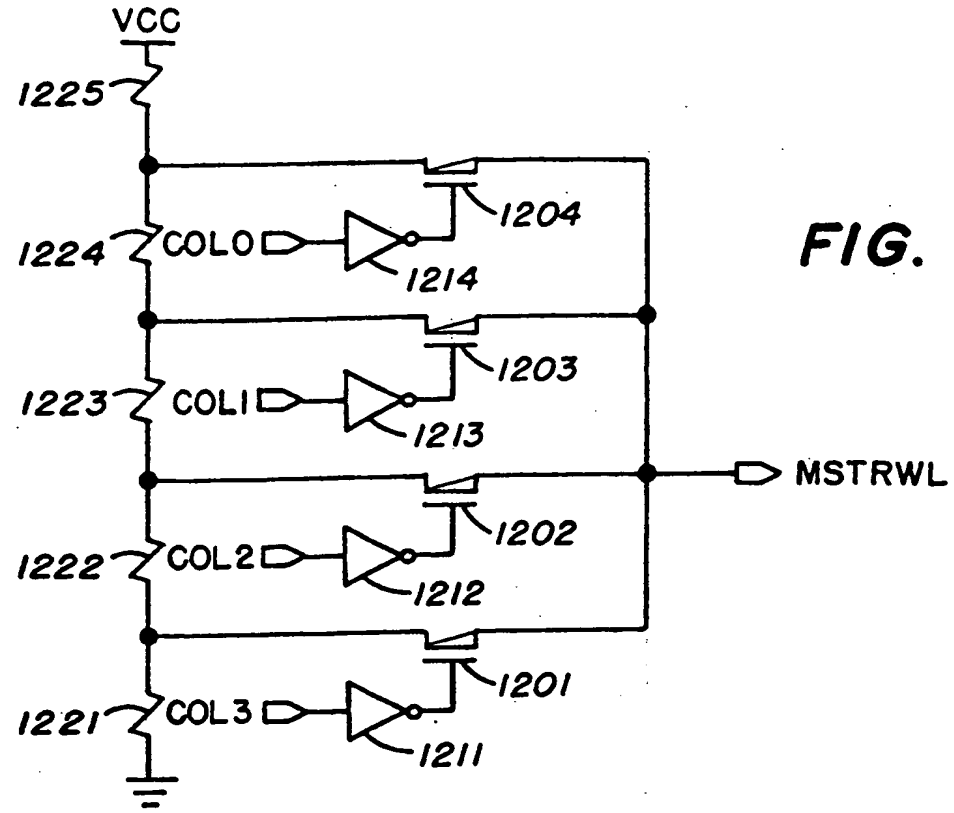

VCC
1225
1224
COL0
1214
1204
1223
COL1
1213
1203
1222
COL2
1212
1202
1221
COL3
1211
1201
MSTRWL

FIG. 12

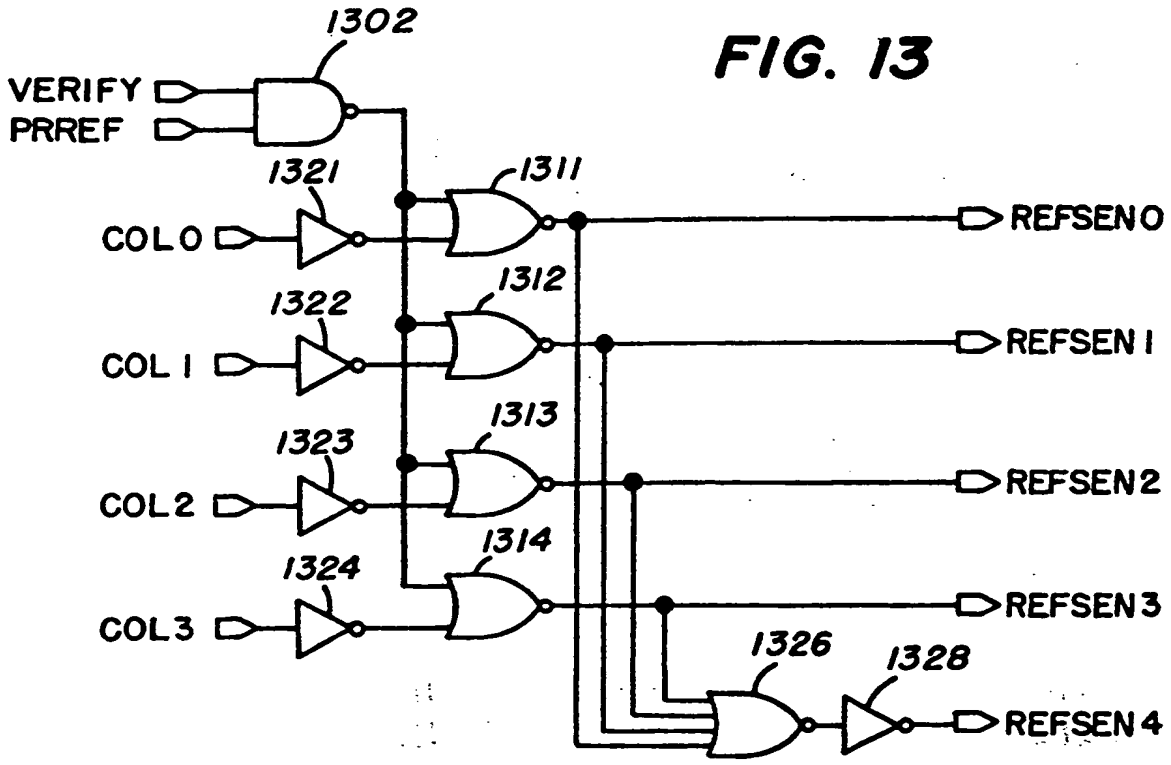
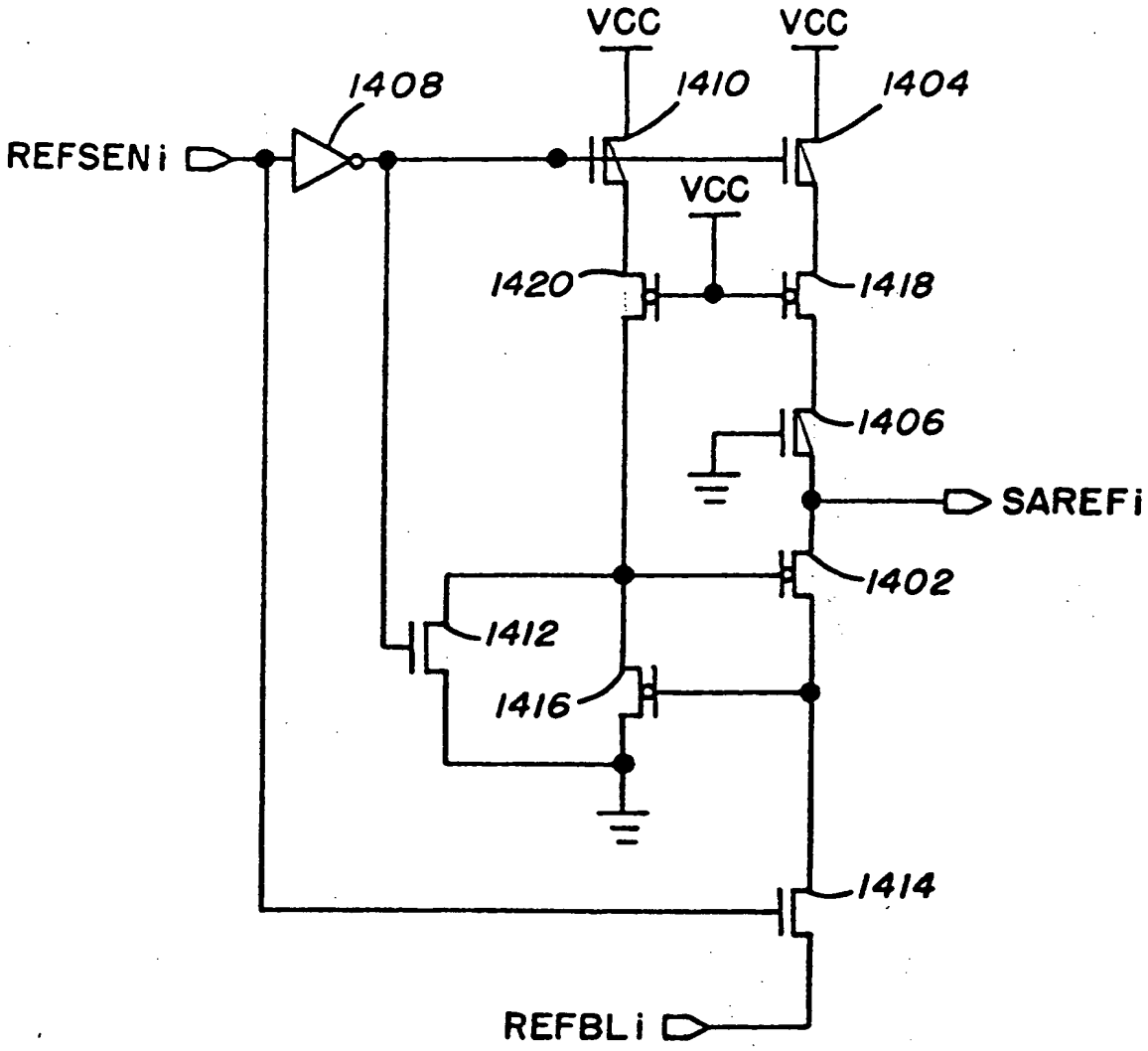

1302
VERIFY
PRREF
1321
COL0
1311
REFSEN0
1322
COL1
1312
REFSEN1
1323
COL2
1313
REFSEN2
1324
COL3
1314
REFSEN3
1326
1328
REFSEN4

FIG. 13

FIG. 14


VCC
VCC
1408
1410
1404
REFSENi
VCC
1420
1418
1406
SAREFi
1402
1412
1416
1414
REFBLi

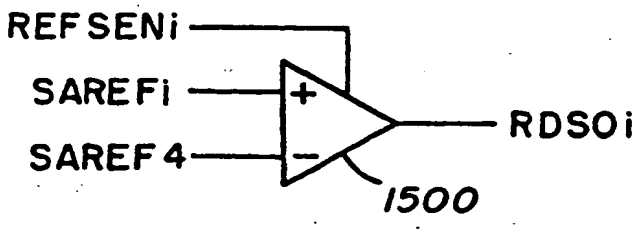

REFSENi
SAREFi
SAREF4
+
−
RDSOi
1500

FIG. 15